Goddard Satellite Data Simulation Unit: Multi-Sensor Satellite Simulators to Support Aerosol-Cloud-Precipitation Satellite Missions

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Goddard SDSU

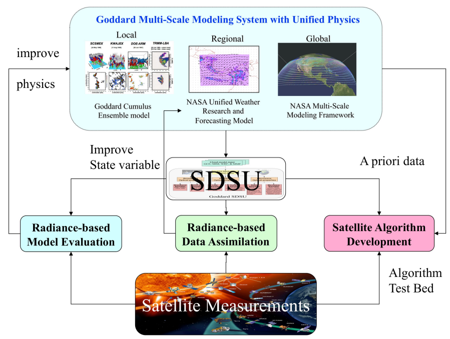
Different aspects of cloud-precipitation structures and properties are being observed from a variety of satellite instruments at present, including A-train constellation satellites (e.g., Aqua, Aura, CloudSAT, CALIPSO, and PARASOL) as well as other single-platform multi-sensor satellites (e.g., TRMM and Terra). Therefore, a combination of multi-platform and multi-frequency satellite observations can provide a more complete view of cloud-precipitation processes, ranging from cloud formulations, to coalescence processes, to the onset of precipitation. In order to facilitate this effort, a comprehensive unified satellite simulator, Goddard Satellite Data Simulation Unit (SDSU), is being developed at the NASA Goddard Mesoscale Dynamics and Modeling Group through multi-institutional collaboration.

The Goddard SDSU is the end-to-end multi satellite simulator unit that can compute satellite-consistent radiance or backscattering signals from visible to microwave spectrum ranges based upon the simulated atmosphere and condensates consistent to the microphysics from a variety of cloud models. These simulated radiances and backscattering can be directly compared with the high-resolution satellite direct observations in order to support i) ***radiance-based model evaluation of aerosol-cloud-precipitation processes, ii) radiance-based aerosol-cloud-precipitation data assimilation iii) multi-sensor satellite retrieval algorithms.***

Software environment
Code language: Fortran90
Library: NetCDF, MPI (optional)
Visual: GrADS
Machine: Unix-flavor laptop, desktop, super clusters. (tested on iMac and Linux cluster).

Simulation options
MPI options: Either file decomposition for a large number of input files or domain decomposition for a large size of model domain.
Model options: GCE, NASA-Unified WRF, NASA MMF.
Microphysics options: Lin-type (Goddard, WSM, Lin) 1-moment bulk cloud microphysics, RAMS 1 (or 2)–moment bulk cloud microphysics, HUCM spectra bin cloud microphysics, GOCART 1-moment aerosols microphysics.
Single scattering components: Mie calculation or using Mie LUTs indexed by T and r_e

Simulators and radiative transfer engine
Passive microwave simulator: Delta-Eddington two-stream scheme [Kummerow 1993, Olson et al. 1996].
Radar simulator: Single scattering scheme [Masunaga and Kummerrow 2005].
Passive visible-IR simulator: Discrete-ordinate scheme [Nakajima and Tanaka 1986 & 1988].
Lidar simulator: Single scattering scheme.
Broadband simulator: Delta-Eddington two-stream adding scheme [Chou and Suarez 1999 & 2001].



Acknowledgment

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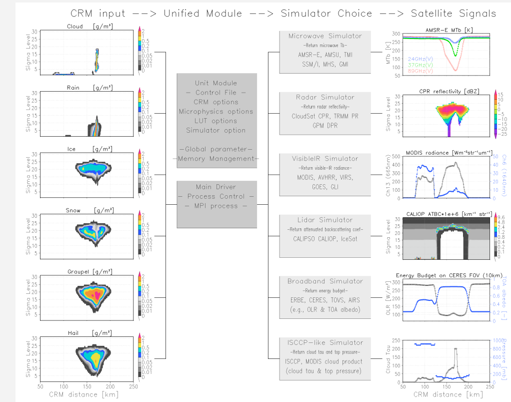
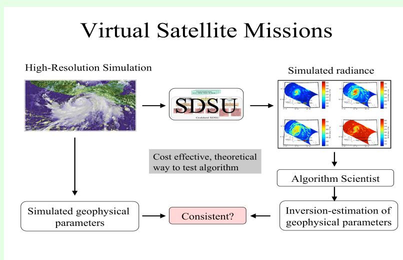
Example

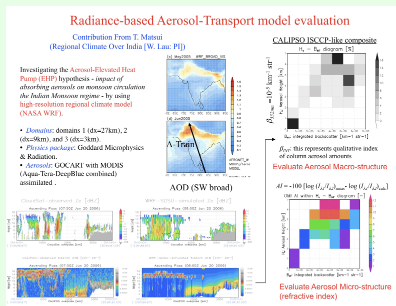
A continental squall line was simulated by the Goddard Cumulus Ensemble (GCE) model with HUCM spectral-bin microphysics using the observed sounding from the Preliminary Regional Experiment for STORM-Central (PRESTORM) (Li et al. 2009). The SDSU simulates the various satellite signals, which can be observable from the A-Train constellation of satellites (Stephens e al. 2002). The cloud-top pressure and cloud optical depth are ~200 hPa and ~200, corresponding to deep convective clouds in the ISCCP category (ISCCP-like simulator, Rossow and Shifer 199). This deep convective cloud raises the TOA albedo up to 0.8, while reducing the Outgoing Radiative Longwave (ORL) down to around 100W/m^2 (Broadband simulator). MODIS NIR (1640nm)-channel radiance is smaller over the MCS due to the presence of ice crystals. The large depression of microwave brightness temperature (*MTb*) at 89GHz is due to the presence of high-density frozen condensates, and the depressions of *MTb* become smaller as a the channel frequency becomes lower (Microwave simulator). The vertical profiles of the MCS can be well observed from the simulated CloudSat Cloud Profiling Radar (CPR) reflectivity, although the reflectivity near the convective core is completely saturated below 10 km due to the strong attenuation effect (Radar simulator). Attenuation is even heavier in the CALIOP attenuating backscattering coefficients (*ATBC*) (Lidar simulator).

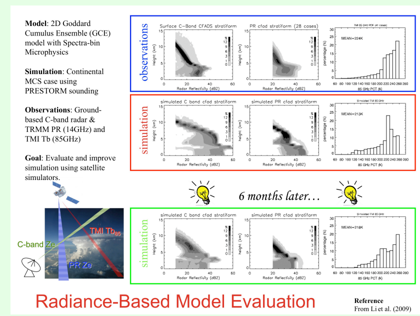
Using the Goddard SDSU, these transformations from model space to satellite radiance space can be done within the unified physics framework; i.e., model-simulated condensate amounts and size distributions as well as profiles of temperature and humidity are consistently used to drive these simulators.

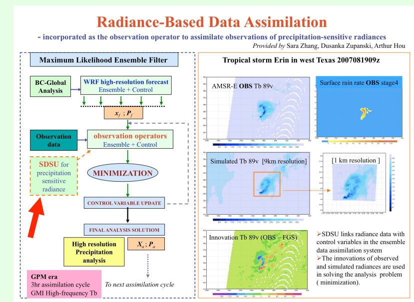


Applications







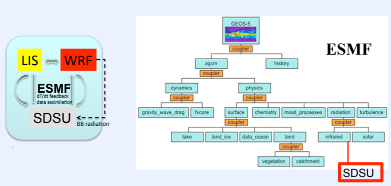


On-Going and Future Works

Online Coupling of Goddard SDSU with NASA-Unified WRF and GEOS-5 GCM via ESMF

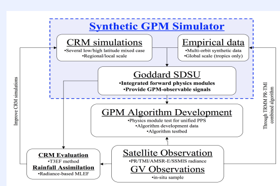
The Earth System Modeling Framework (ESMF) is high-performance, flexible software infrastructure to increase ease of use, performance portability, interoperability, and reuse in climate, numerical weather prediction, data assimilation, and other Earth science applications. The ESMF defines an architecture for composing complex, coupled modeling systems and includes data structures and utilities for developing individual models.

At present, Goddard SDSU and NASA-Unified WRF are coupled offline. This is completely fine for most of the applications descried above. However, if the Goddard SDSU is online coupled with the Nu-WRF via ESMF, namely satellite-observable signals can be computed during an integration of atmosphere-model simulation without dumping model outputs. Thus, it should be useful particularly for operational weather forecasting using radiance-based data assimilation. In addition, if coupled online, the radiation module within the WRF can be completely replaced by the broadband simulator in the Goddard SDSU, and then more realistic slant-path or full 3D broadband radiative transfer module should be flexibly developed.

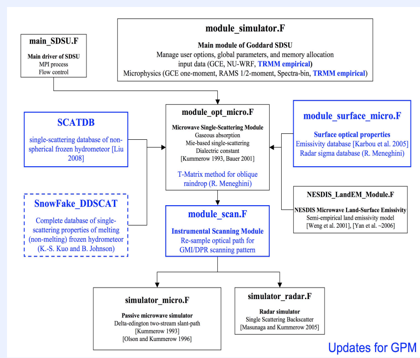


Synthetic GPM Simulator

The next-generation Global Precipitation Measurement (GPM) mission core satellite will have a better capability of detecting light rain and falling snow in middle and high latitudes via a dual-frequency radar (i.e., the GPM dual-frequency precipitation radar or DPR) and a multi-frequency radiometer (i.e., the GPM Microwave Imager or GMI). This improvement requires more complex rainfall algorithms that can handle multi-sensor and multi-frequency signals of warm/cold/mixed rain over land/ocean in the Tropics as well as high latitudes. To facilitate such algorithm development, this project aims to develop a Synthetic GPM Simulator composed of a unified GPM instrument simulator (forward model) coupled with multiple CRM simulations and a TRMM-derived empirical cloud-precipitation database. The Synthetic GPM Simulator will be built upon the existing multi-sensor satellite simulator, the Goddard Satellite Data Simulation Unit (SDSU).



Development of the Synthetic GPM Simulator supports the GPM unified algorithm architecture by sharing physics modules (i.e., single-scattering, radiative transfer, and microphysics) and an ancillary database (surface emissivity and surface radar backscatter) needed for doing retrievals among GPM algorithm teams. Also, the simulator-generated testbed will support GPM pre-launch algorithm verification phase 1 (evaluation of algorithms using regional CRM simulations and/or real data retrieval at select locations, 01/11 ~ 01/12) and phase 2 (statistically robust global verification of algorithms using multi-orbit synthetic data generated from satellite simulators, 01/13 ~ 01/13). Although the main purpose is to support GPM algorithms, development of the Synthetic GPM Simulator will also support radiance-based CRM evaluations as well as radiance-based rainfall assimilation systems.



An above figure depicts an updated architecture of the Goddard SDSU suitable for the GPM mission. Upgrades includes **IO module**, **single-scattering module**, **land-surface emissivity module**, **surface radar signals**, and new **scanning module**. Upon completion of the upgrades, we will create modularized physics routines and database management that can be readily shared between different GPM algorithm developers. The ultimate purpose of this modularized approach is to allow consistent physics assumptions to be used for the DPR, DPR+GMI, and enhanced GMI algorithms for the generation of the testbed (*from the U.S. GPM algorithm team meeting at NASA GSFC on 31 May 2009*). All of the physics modules and ancillary datasets will be shared with the GPM algorithm teams.

Joint EarthCARE Simulator

EarthCARE mission will measure vertical profiles of aerosol-cloud processes and interactions and their radiative properties via Backscatter Lidar (ATLID), Doppler Cloud Profiling Radar (CPR), Multi-Spectral Imager (MSI), Broadband Radiometer (BBR). In order to support multi-sensor satellite mission, we begin developing Joint EarthCARE Simulator based on the framework of Goddard Satellite Data Simulation Unit (SDSU). The main part is composed of sensor simulators for visible-IR imager, broad-band radiometer, radar, and lidar based on plane parallel RSTAR code, MSTRAN, and single scattering approximation with simple multiple scattering corrections. These simulators are designed to support EarthCARE's algorithm developments. In addition, we plan to hardwire RSTAR optical properties with 3D Monte Carlo Atmospheric Raditive Transfer Simulator (MCARaTS) for simulating complex 3D photon interactions. Passive microwave simulators are also included for combined analysis of constellated microwave radiometers in the EarthCARE periods.